

**&
DECOMPRESSION
SICKNESS**

***Aeromedical / Environmental Course 6
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U.S.ARMY SCHOOL OF AVIATION
MEDICINE

&

NAVAL OPERATIONAL MEDICAL
INSTITUTE

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What is Hyperbaric Oxygen Therapy?



- Hyperbaric oxygen is a method of therapy in which the patient breathes 100% oxygen at pressures greater than normal atmospheric (>14.7 psi) pressure.
- Hyperbaric oxygen therapy involves the **systemic** delivery of oxygen at levels 2-3 times greater than atmospheric pressure.

What is NOT HBO Therapy?

- Breathing 100% oxygen at sea level pressure / 1 Atmosphere (1 ATA) / 14.7 PSIA is not hyperbaric oxygen therapy.
- Topical Oxygen Therapy - exposing parts of the body to 100% oxygen, is also not HBO.

HBO PHYSIOLOGICAL EFFECTS



- **HYPEROXYGENATION**
- **NEOVASCULARIZATION**
- **ANTIMICROBIAL ACTIVITY**
- **DIRECT PRESSURE**
- **VASOCONSTRICTION**
- **ATTENUATION OF
REPERFUSION INJURY**

HYPEROXYGENATION

- Provides **immediate** aerobic support to tissues with compromised blood flow.
 - Room Air Dissolved plasma O₂ at sea level = 0.3ml/100cc
 - 100% O₂ Dissolved plasma O₂ at sea level = 1.5ml/100cc
 - 100% O₂ Dissolved plasma O₂ at 66 ft = **6.0ml/100cc**
- Resting Tissue Requirement for O₂ 5-6ml/100cc

Dissolved plasma O₂ is adequate for tissues without any contribution from Hemoglobin bound O₂
- Increasing the diffusing distance of oxygen from functioning capillaries - **4 X**

HYPEROXYGENATION



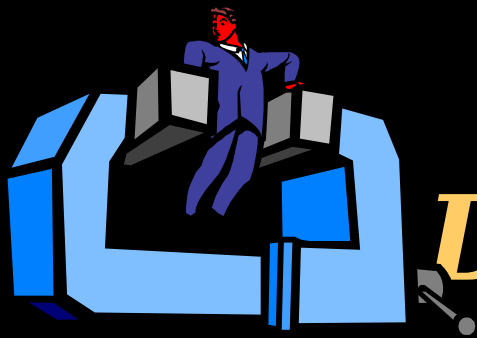
- Only a temporary measure.
- Can serve to buy time and maintain tissue viability until corrective measures can be implemented.
 - Obtain blood type and cross for rare blood types.
- Acute CO poisoning (*Most common cause of death by poisoning in U.S.*)
 - Hyperbaric O₂ reduces 1/2 life of CO-Hgb from 5 hours in patients breathing RA to less than 20”.

NEOVASCULARIZATION

- An indirect and delayed response to hyperbaric oxygen exposure.
- Therapeutic effects include:
 - enhanced fibroblast division
 - neoformation of collagen
 - capillary angiogenesis
 - late radiation damaged tissue, refractory osteomyelitis and chronic soft tissue ulceration.

ANTIMICROBIAL ACTIVITY

- Inhibits production and inactivates toxin in ***Clostridial perfringens*** infections (Gas Gangrene).
- Enhances phagocytosis and white cell oxidative killing
- Enhances Aminoglycoside activity.
- Demonstrated prolonged post-antibiotic effect, when hyperbaric oxygen is combined with tobramycin against ***Pseudomonas aeruginosa***.



DIRECT PRESSURE

- Boyle's Law is utilized to reduce the volume of intravascular or other free gas.
 - This is the basis for hyperbaric oxygen therapy as the standard of care for decompression sickness and cerebral arterial gas embolism (CAGE).
- CAGE can be a frequent iatrogenic event in modern neuro or CT surgical procedures.
 - It results in significant morbidity and mortality and remains grossly under-diagnosed.



VASOCONSTRICTION



- Occurs without concomitant hypoxia
- Helpful in managing intermediate compartment syndromes or other acute ischemias in injured extremities, and reducing interstitial edema in grafted tissue.
- Can significantly decrease fluid resuscitation requirements for acute burn wounds.

ATTENUATION OF REPERFUSION INJURY

- Following an ischemic interval, the total injury pattern is the result of two components:
 - » a **direct** irreversible injury component from hypoxia,
 - » an **indirect** injury which is largely mediated by the inappropriate activation of leukocytes.
- Hyperbaric oxygen reduces the **indirect** component of injury by *preventing* such activation.
 - » Marginal tissue preservation that may have been otherwise be lost to ischemia-reperfusion injury.

RECOMMENDED INDICATIONS for HBO

- **Air/Gas Embolus (acute)**
- **Decompression Sickness**
- **Carbon monoxide poisoning and smoke inhalation**
- ***Clostridial* myonecrosis (gas gangrene)**
- **Anaerobic Infection (*Actinomycosis*) or other necrotizing Soft Tissue Infections**
- **Crush injury, compartment syndrome, and other acute traumatic ischemias**
- **Intracranial Abscess**
- **Exceptional Blood Loss (anemia)**
- **Cyanide Poisoning**
- **Enhancement of healing in selected problem wounds**
 - **skin grafts or compromised flaps**
 - **Diabetic Wounds (venous & decubitus Ulcers)**
 - **Necrotizing soft tissue infections (subcutaneous tissue, muscle, fascia)**
 - **Osteomyelitis (refractory)**
 - **Radiation Necrosis**
 - **Thermal burns**

DECOMPRESSION SICKNESS

- Is an illness caused by reduced atmospheric pressure on the body that results in formation of bubbles of inert gas (Nitrogen) within body tissues.
- Annual U.S. DCS *hits* = 500 (100 are fatal)
- The role of the flight surgeon in the diagnosis and initial management of DCS is crucial; inadequately treated, DCS can lead to disability or death.

HISTORY

- Robert Boyle first described DCS in 1670.
- Noted a bubble in the eye of a snake which he had exposed to decreased atmospheric pressure.
- The first description of human DCS was published by Triger in 1841.
 - Coal miners working deep under ground suffered from muscular cramping and pains after coming to the surface.
 - Symptoms were alleviated upon return to the compressed air environment.

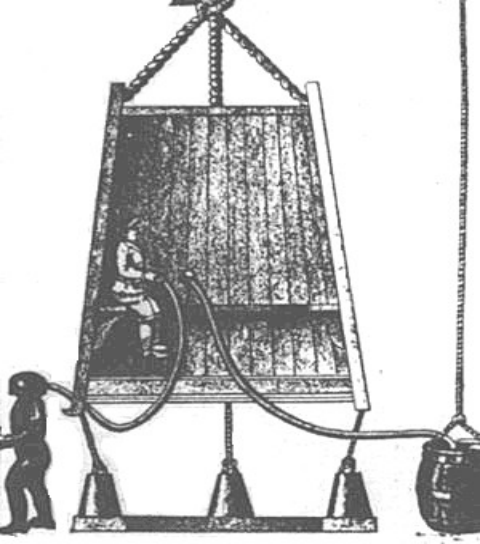
HISTORY (Continued)

- Paul Bert (a French physiologist) in 1878 noted that the symptoms of DCS were caused by bubbles of nitrogen which evolved due to a rapid decrease in atmospheric pressure.
- Paul Bert also discovered that pure oxygen is toxic (Seizures) when breathed under pressures greater 33 feet (2 atmospheres) for extended periods.



***HISTORY** (Continued)*

- During late 1800's the term "**Bends**" was coined as a synonym for DCS.
 - Fashionable ladies of the day wore corsets that caused them to assume a bent over posture which was referred to as the "Grecian bend."



HISTORY (Continued)

- **"Caisson's disease"** was coined as another synonym for DCS.
 - During the construction of the Brooklyn Bridge starting in January 1870, many workers developed DCS from working in pressurized caissons used to build the bridge abutments.
 - Brooklyn caisson - 44 feet, bearing on bedrock
 - New York caisson - 78 feet, bearing on sand
 - 1872 Roebling is stricken by Caisson disease, becoming an invalid, he supervises the building of the bridge from his his bedroom.

HISTORY (Haldane)

- The British Royal Navy was noting a high incidence of DCS in its military divers, hired Haldane to perform DCS research.
- Through extensive animal experiments, Haldane concluded that the body could usually tolerate a **two-to-one reduction** in ambient pressure without symptoms.
- His findings were published in 1908, and were the basis of the first decompression tables.

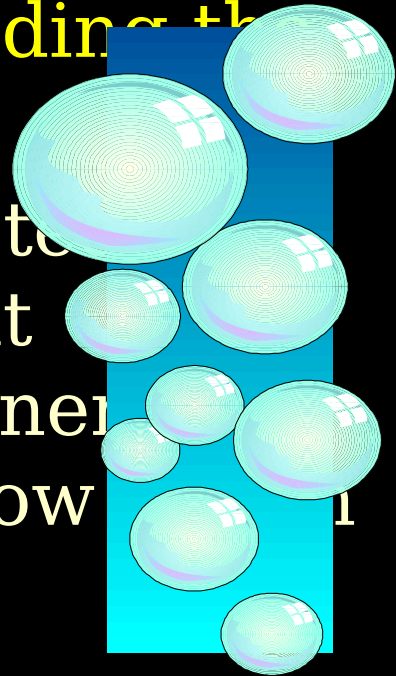
HISTORY (Continued)

- In 1919, Herringer formulated the theory that the mechanisms of diving and altitude DCS were identical.
- No DCS in early powered flight “No Power”
- During World War II, decompression sickness became a significant problem, stimulating a great deal of DCS research.
- Research discovered that the breathing of **pure oxygen** prior to decompression exposure lowered the risk of DCS.

ETIOLOGY OF DCS

(Henry's Law)

- Henry's Law
 - “the amount of inert gas which is dissolved in body tissues is directly proportion to the inert gas partial pressure surrounding the person prior to decompression”
- DCS occurs when a person is subjected to sudden reduction in ambient pressure that causes inert gas bubbles to form and grow in body tissues and vascular spaces.



“SUPERSATURATION”

- During decompression, the partial pressure of inert gas (Nitrogen) in the ambient environment decreases. Nitrogen equilibrates by leaving the body tissues, traveling in the blood to the lungs, where it is expelled through expired air.
- If decompression occurs faster than Nitrogen can unload, a condition of supersaturation exists.
- If the amount of dissolved Ni exceeds the ability of the tissues to hold it in solution, the nitrogen *comes out of solution in the form of bubbles.*

“Critical Supersaturation point ”

Nitrogen Uptake in the Body

- Fast Tissue

NITROGEN UPTAKE UNDER INCREASED AMBIENT PRESSURE

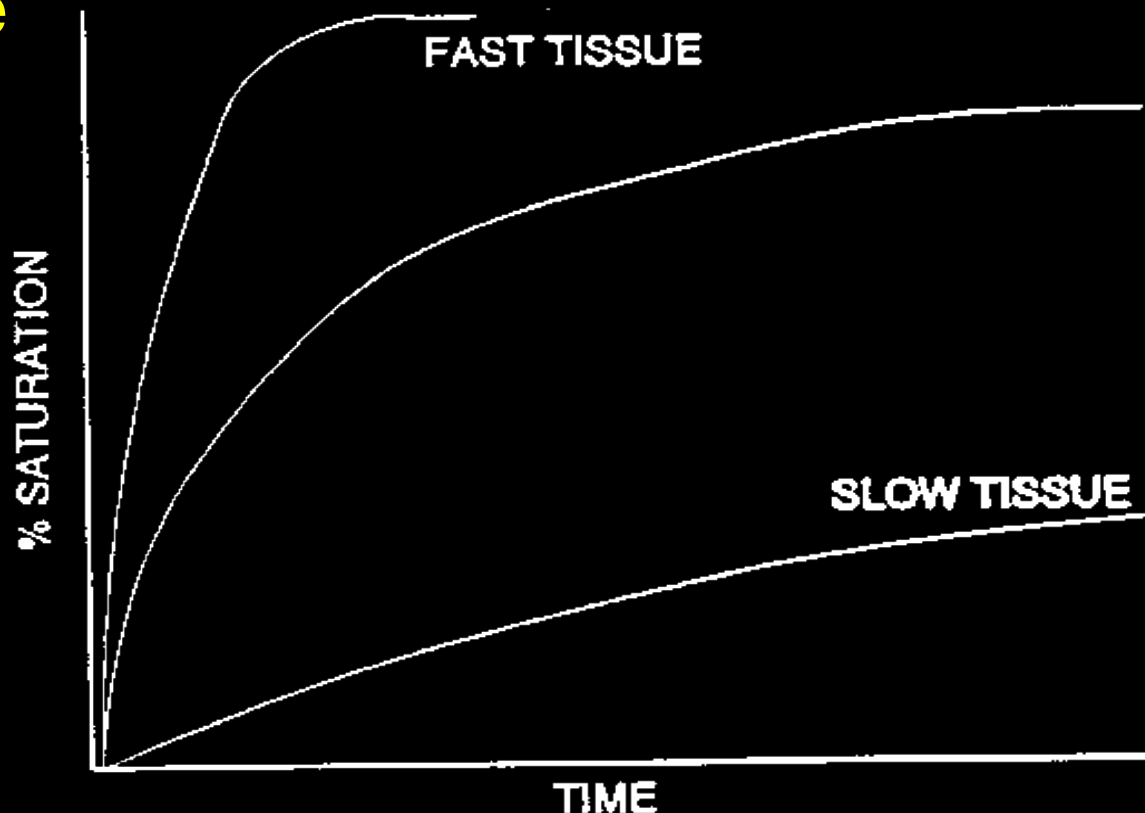
- Hi H₂O Tissue
- Muscle

- Intermediate

- Fat

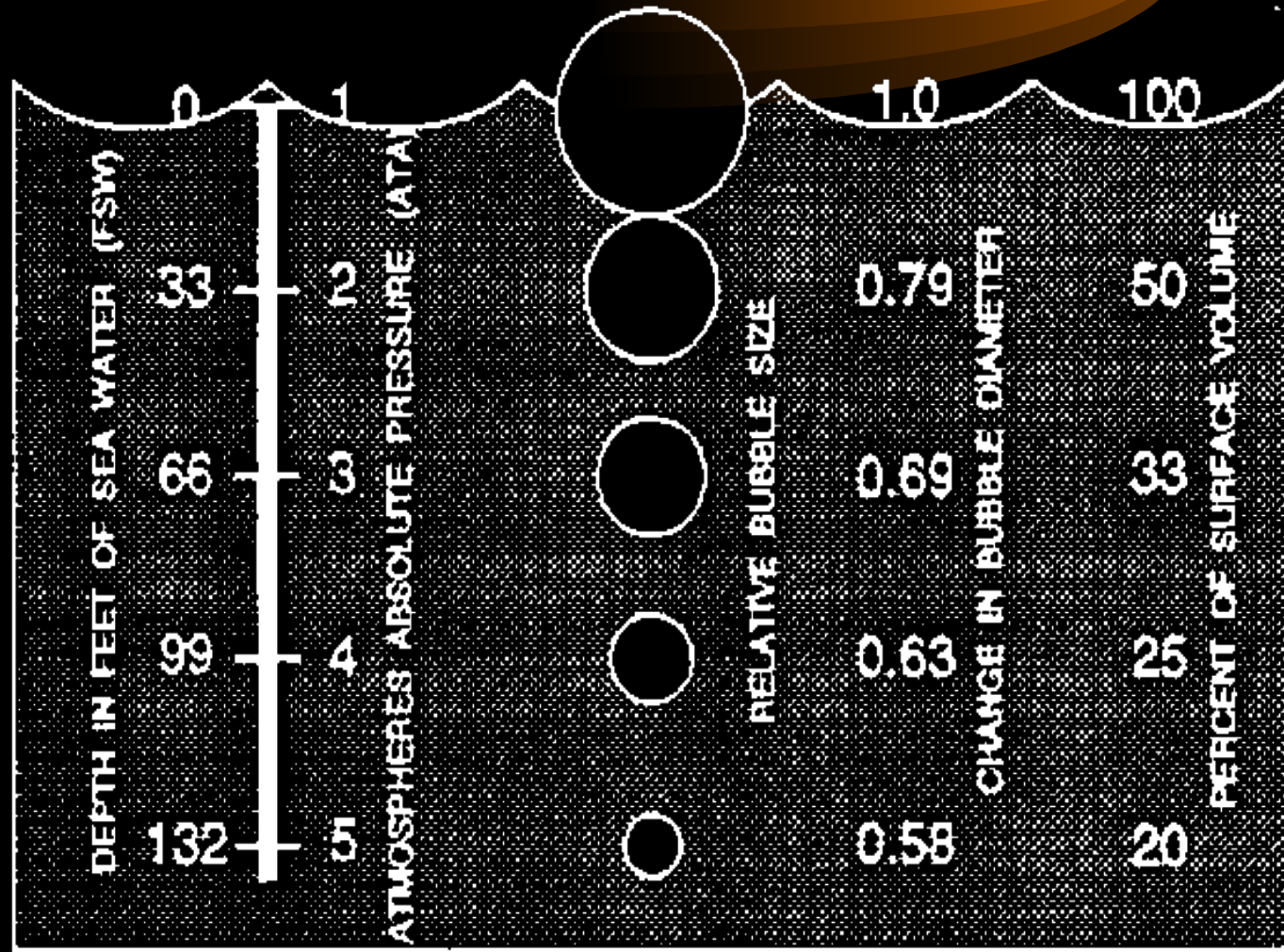
- Slow Tissue

- Bone



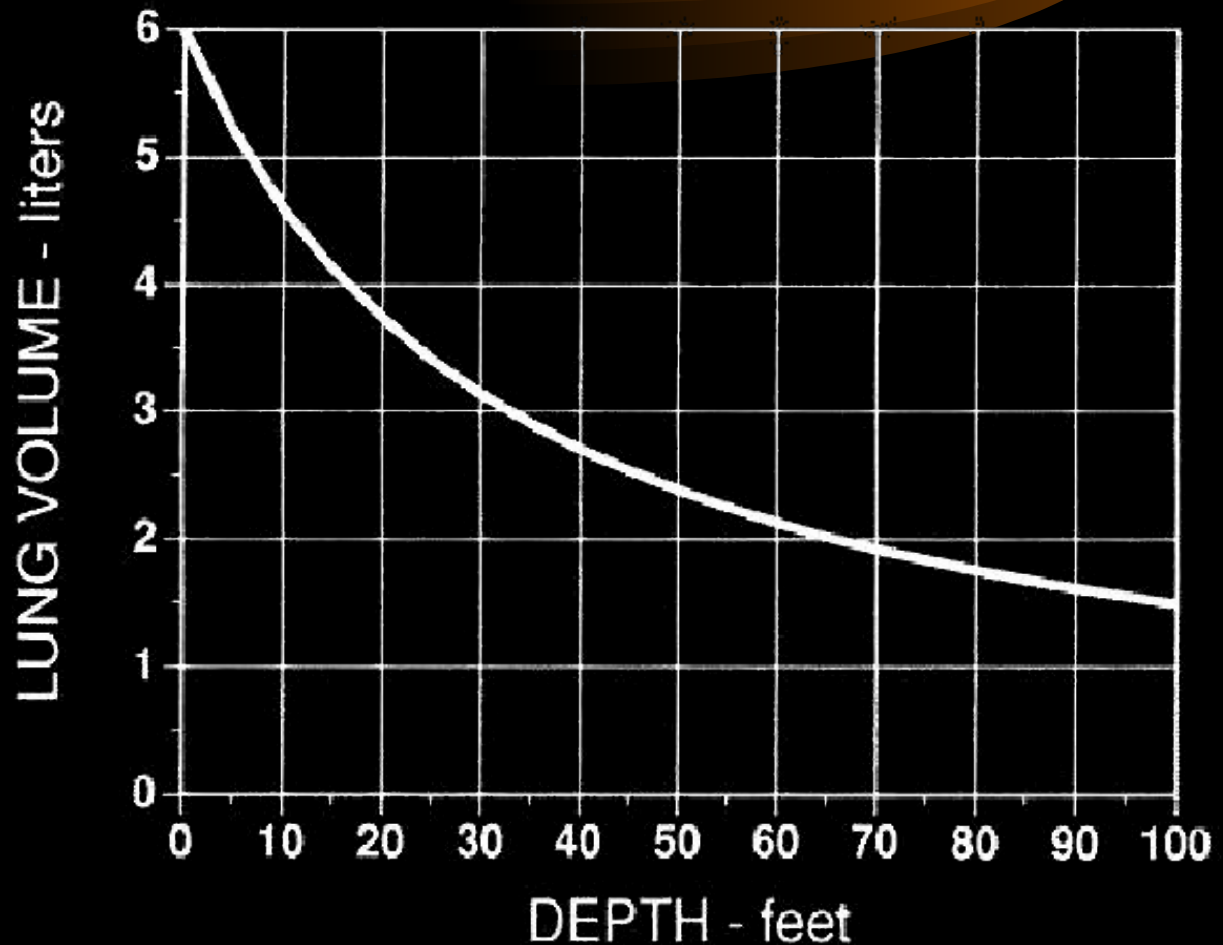
Boyle's Law

“With
Temperature Constant,
the Volume
of a gas
varies
indirectly
with the
ambient
pressure.



Boyle's Law

- Boyle's law *at work* in surface breath-holding!
- Notice the most rapid change in Volume occurs in the first 20'



ETIOLOGY OF DCS

(Boyle's Law)

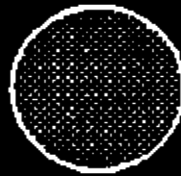
- Once the bubbles are formed ***any decrease in pressure*** causes bubbles to grow.
- ***Any increase in pressure***, such as treatment in a hyperbaric chamber, cause bubbles to shrink.



PRESSURE EFFECTS ON BODY SYSTEMS

EFFECTS OF PRESSURE ON BODY SYSTEMS

COLLAPSIBLE
STRUCTURE



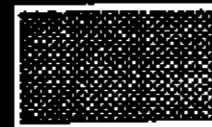
BOWEL

MOBILE
BOUNDARIES



EAR ?

IMMOBILE
BOUNDARIES



TOOTH

VENTED



SINUS

VENTED &
MOBILE



EAR

BUBBLE EFFECTS ON THE BODY

- **Mechanical Effects**

- Bubbles can be detected by Doppler techniques once they reach a size of 40 to 50 microns, especially if there are many of them.
- A bubble growing in the tissues will displace and deform adjacent structures causing:
Impingement on nerve endings, tearing of tissues takes place and mechanically obstruct vessels.
 - Leading to distal ischemia. If ischemia is in the CNS may result in neurologic symptoms.

BUBBLE EFFECTS ON THE BODY

- **Biochemical Effects**

- Intravascular bubbles act as foreign bodies, causing enzyme release, enzyme activation, and release of vasoactive substances causing leakage of fluids from the intravascular to the extravascular spaces.
- Platelets and red blood cells tend to clump on the surface of bubbles. As venous bubbles produce platelet aggregation, there is a release of vasoactive substances such as Serotonin and Epinephrine, leading to vasoconstriction.

*Let's Take a 10
Minute
Break !!!!!*

CLINICAL MANIFESTATIONS OF DCS



DCS symptoms have been
classically grouped
into two types:

**Type I DCS & Type II
DCS**

Type I DCS



- Joint pain (musculoskeletal) ***
- Cutaneous pain symptoms
- Pain and swelling within the lymphatics.

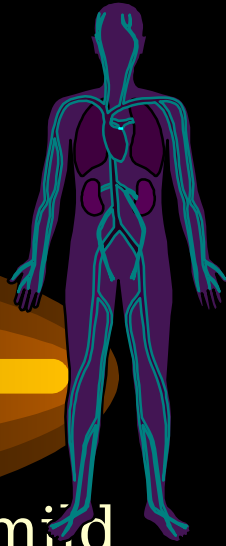
Type I DCS

(Musculoskeletal)

- **Joint pain is by far the most common type**, approximating 90% of all cases of DCS
- Location: Mostly large joints of the body (elbows, shoulders, hip, wrists, knees, ankles) The shoulder is the most common site of joint pain.
- Often the pain is described as being "deep" and throbbing & tends to radiate or extend along the limb. The pain ranges from mild (a "niggle") to excruciating.
- Active and passive motion of the joint aggravates the pain.
- Pain can occur at altitude, during the descent, or many hours later.

Type I DCS

(Cutaneous Manifestations)



- Sensations include pruritis (itching), formication, mild stinging or pin pricks (paresthesias), hot or cold sensations, and sometimes numbness.
- Symptoms may be associated with a fine scarletiform rash caused by the movement of nitrogen through sweat glands. No treatment required.
- ***Cutis Marmorata*** (marbling) a raised and has a cyanotic discoloration, possibly intensely pruritic. This is a bona fide form of DCS which should be treated by recompression

Type I DCS

Cutis Marmorata

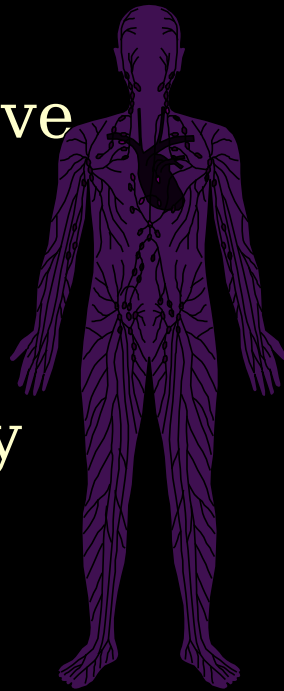


(c) University Erlangen,
Department of Dermatology
Phone: (+49) 9131- 85 - 2727

Type I DCS

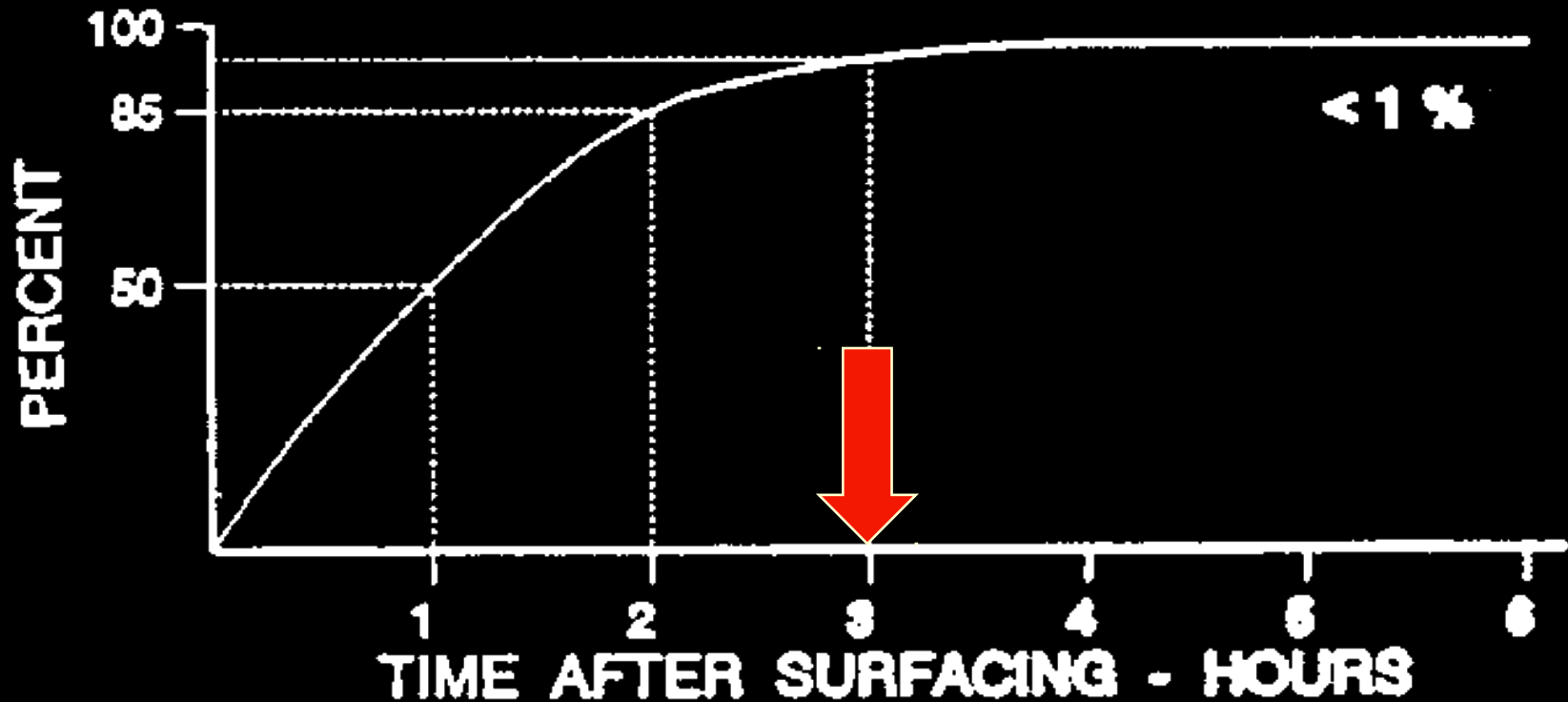
(Lymphatic Manifestations)

- Pitting edema is caused by blockage of the lymphatics by physical obstruction by the bubble.
- A finding in the vicinity of a painful joint which may have been the presenting symptom.
- Hyperbaric therapy may be used to help relieve pain, decrease swelling, and possibly reduce more serious manifestations from developing later.
- Peripheral swelling may disappear completely during recompression or may take days or weeks for resolution.



DCS Symptom Onset

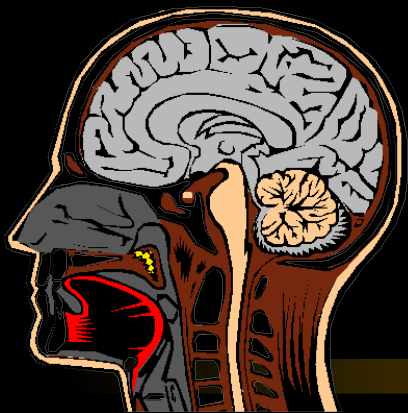
TIME OF SYMPTOM ONSET



Type II DCS



- Type II DCS comprises serious symptoms or signs involving the central or peripheral nervous system, or the cardiopulmonary system.
- Any aviator experiencing Type II DCS requires rapid treatment to prevent permanent injury or death.



NEUROLOGIC

(Brain)

- Confusion, memory loss, headache, scotoma, tunnel vision, diplopia, or blurry vision, dizziness, vertigo, seizure, unconsciousness
- Unexplained extreme fatigue or behavior changes
- Nausea & vomiting may occur.





NEUROLOGIC

(Spinal Cord)

- Abnormal sensations such as burning, stinging, and tingling around the lower chest and back
- Symptoms may spread from the feet up and may be accompanied by ascending weakness or paralysis
- Girdling abdominal or chest pain

NEUROLOGIC

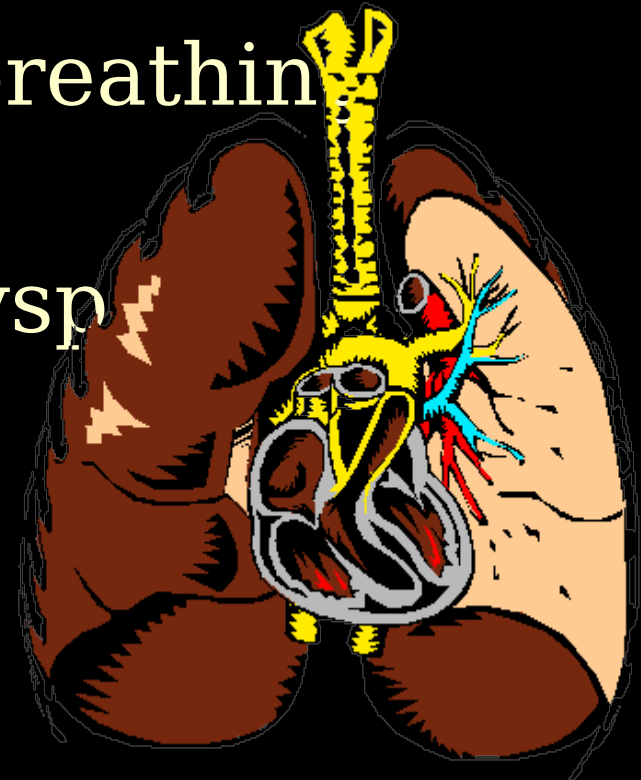
(Peripheral Nerves)



- Urinary and rectal incontinence
- Abnormal sensations, such as numbness, burning, stinging and tingling (paresthesia)
- Muscle weakness for twitching

Lungs “Chokes”

- Burning deep chest pain (under the sternum)
- Pain is aggravated by breathing
- Shortness of breath (dyspnea)
- Dry constant cough



FACTORS AFFECTING DCS INCIDENCE AND SEVERITY





ALTITUDE

- Increasing the altitude contributes to an increased incidence of DCS.
- Most commonly cited minimum "bends altitude" is 25,000 feet.
- The lowest recorded occurrence of DCS in a healthy individual has been 18,000 feet.
 - Lower altitudes may precipitate DCS if aggravating factors are present... recent SCUBA diving within previous 24 hours.

TIME AT ALTITUDE



- Increased time at altitude contributes to a greater incidence of DCS.
- Increased time at altitude permits growth of bubbles that are otherwise innocuous at a smaller size.
- A rapid descent after a cabin decompression is critical to minimizing the risk of DCS complications.

RATE OF ASCENT

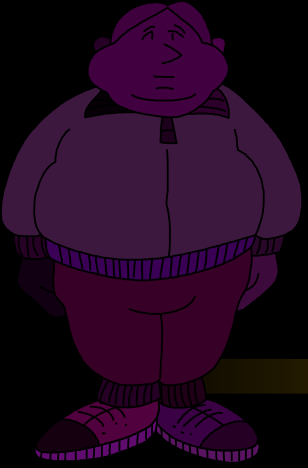


- A faster rate of ascent to altitude contributes to a greater incidence DCS.
- A slow ascent permits excess nitrogen to be transported in solution from the tissues to the lungs so a supersaturated state is less likely.



EXERCISE

- Exercise during altitude exposure increases DCS incidence. Several factors that may contribute to this effect include:
 - the sliding movement of one tissue against another, causing a shearing action and encourage bubble formation
 - contracting skeletal muscles, which cause local areas of blood cavitation and turbulence, encouraging bubble formation.

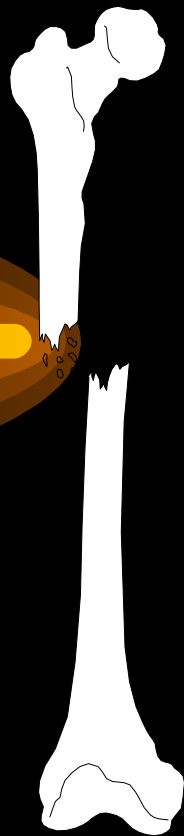


BODY FAT

- Earlier studies have emphasized that an increased proportion of body fat increases the probability of DCS.
- There is no scientific evidence to validate whether or not obesity increases the probability of diving DCS.
- When body fat, rather than body weight, is examined in relation to DCS, it is clear that **obesity does increase the probability of DCS**, especially after long, deep dives.

PREVIOUS INJURY

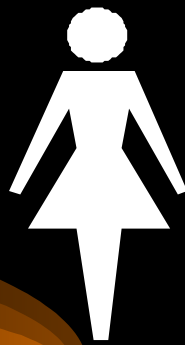
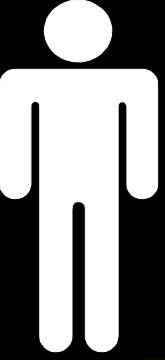
- There are numerous accounts of bends pain occurring preferentially in areas that have been previously injured.
- Pain not actually associated with bubble formation may mimic bends pain. Since diagnosis under these conditions is difficult, such pain must be carefully evaluated.
- Some studies have suggested that changes in local perfusion and an increase in gas micronuclei formation in the injured tissue may be responsible for this effect.





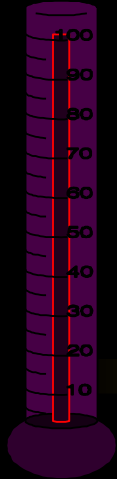
AGE

- Before the age of about 40 years
 - No correlation between age and DCS incidence is clearly demonstrated.
- After 40 years
 - DCS incidence increases with increased age. This increase occurs in both compressed air workers and aviators
 - A 3X increase in incidence between the 19-25 year old and 40-45 year old age groups.



GENDER

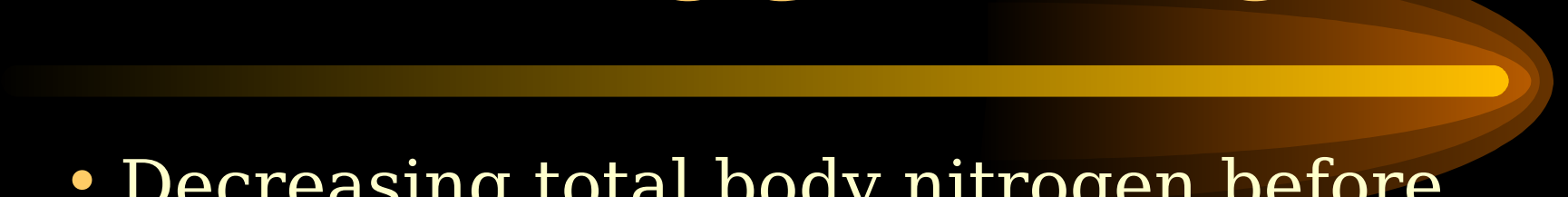
- There is some information which suggests females are 3 to 4 times more prone to DCS than males exposed to similar altitude conditions.
- Women may also be at increased risk of DCS at the time of menses.
 - The mechanism for this observation is unknown.



TEMPERATURE

- No correlation exists between the frequency of DCS and the ambient temperature in the range of 21.1° C, to 34.3°C.
- When temperature of -23.3° C, the incidence of DCS is twice that at 21.1° C
- Temperature, may be an important factor in cold water diving activities, but is usually of little or no consequence to altitude-induced DCS.

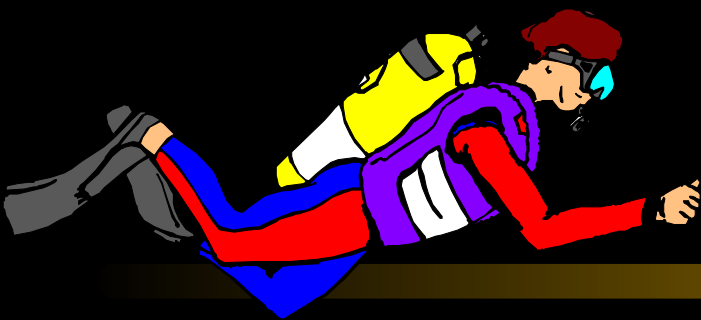
DENITROGENATION



- Decreasing total body nitrogen before decompression reduces DCS incidence.
- Breathing 100% oxygen establishes a diffusion gradient to offload nitrogen from the blood to the lungs.
- Denitrogenation with oxygen, also called "prebreathing", is the current prophylaxis for DCS.



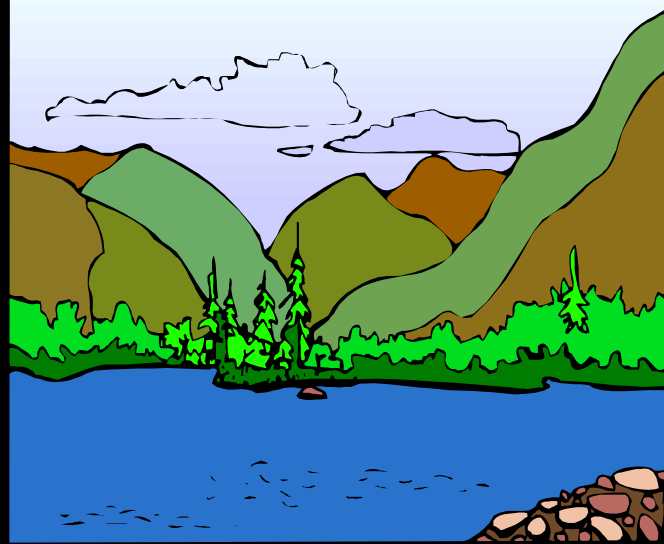
- Exposures occurring in rapid succession within minutes or a few hours of the previous exposure increase the incidence of DCS during the subsequent exposure.



Diving

- Safe decompression limits vary with the time and the depth of the dive.
- If a diver exceeds these safe limits either through missed decompression stops to the surface or through multiple ascents during a dive there will be an enhanced presence of venous gas bubbles.
- If a diver exposes himself to a repetitive dive, the residual nitrogen remaining within the tissues may increase the likelihood of DCS.

High Altitude Diving



- Sea-level decompression tables become less safe as altitude increases.
- Special decompression schedules are available from the US Navy when divers are exposed to elevations above 6000 feet.



Flying After Diving

- SCUBA diving followed by altitude exposure vastly increases the incidence of DCS.
- Flying decreases the minimum altitude at which DCS manifestations begin. This can be demonstrated even during flight on aircraft equipped with pressurization systems (whose cabin altitudes are usu. 5 K - 8 K feet).
- Flying following diving potentates bubble formation by theoretically increasing the supersaturation ratio beyond the critical threshold, even after an uneventful decompression to sea level.

Individual Variability

- There is great variability in individual susceptibility to DCS. Under the same conditions, persons develop DCS while others show no signs or symptoms.
- There is a tendency for a person who develops DCS under given conditions to again develop DCS later under similar conditions.

TREATMENT OF DCS

(Initial Response to DCS - Onset During Flight)

- **1.) Descend (or return to chamber ground level)**
 - The increased pressure serves to compress bubbles.
- **2.) Use 100% oxygen from an aviators oxygen mask during the entire descent.**
 - 100% oxygen enhances nitrogen elimination by increasing the diffusion gradient of nitrogen and relieves tissue hypoxia.
- **3.) Get qualified medical help.**
 - In the case of altitude chamber induced DCS, students should be instructed to be aware of the possibility of postflight symptoms.

Medical Management of DCS



- **Continue to provide 100% oxygen delivery via a tight fitting aviator's mask.**
- **Initiate Intravenous fluids (NS or LR)**
 - Used to prevent hemoconcentration which can occur with intravascular volume loss.
 - An infusion rate of **250 cc/hour** is recommended for the first few hours. One should not be overly concerned with overhydration in a young, otherwise healthy aviator.

Medical Management of DCS



- **Obtain a complete history and perform a complete physical exam**
 - Include a detailed neurologic exam.
 - Do not ignore seemingly minor symptoms.
 - They can quickly become major
- 

Medical Management of DCS

- **Contact the local Hyperbaric Center**
 - Any known or suspected cases of DCS should be discussed with a trained hyperbarics physician.
 - This physician can provide valuable information and advice regarding treatment and patient transportation options.



Medical Management of DCS

- Patients with Type I DCS only (joint symptoms) who become asymptomatic during descent or at ground level prior to evaluation.
 - Maintained on 100% oxygen for 2 hours following symptom resolution.
 - After 2 hours, a complete exam, with detailed neurologic exam, should be done.
 - If all is normal, no further treatment is needed, other than observation.

Medical Management of DCS (With Chamber Available)



- If the patient has continuing symptoms, they should be moved to a recompression chamber and immediately treated on the proper treatment table.
 - The effectiveness of treatment decreases as the length of time between the onset of symptoms and the treatment increases.

USN Treatment Tables

(Examples)

TREATMENT TABLE 7 DEPTH/TIME PROFILE

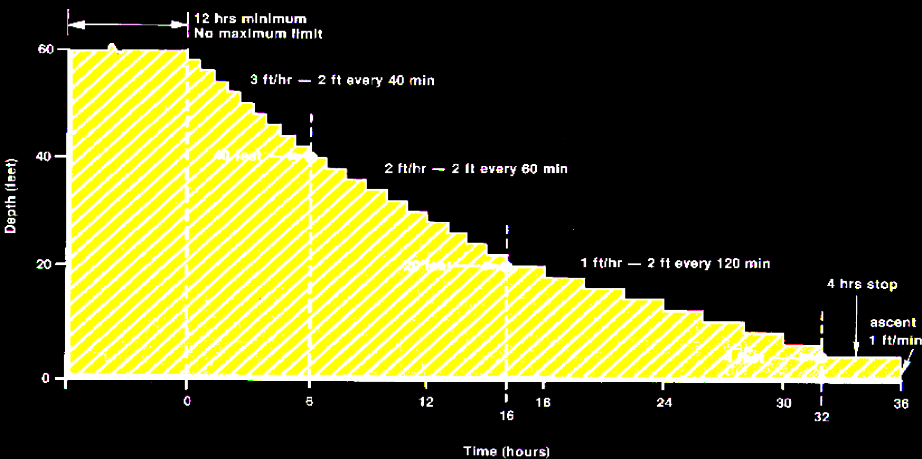


TABLE 6A DEPTH/TIME PROFILE

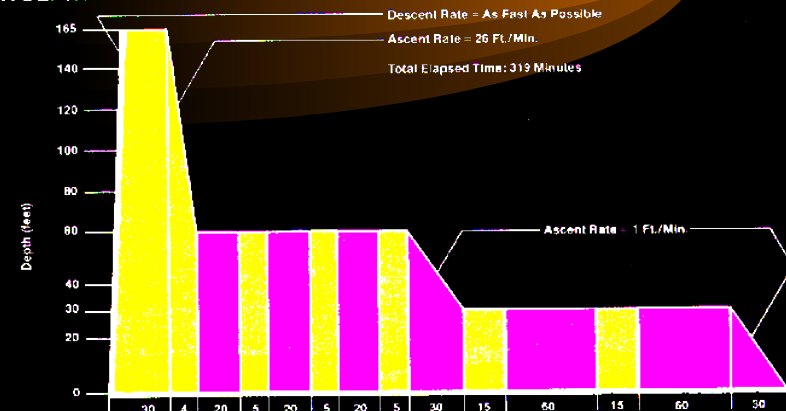


TABLE 4 DEPTH/TIME PROFILE

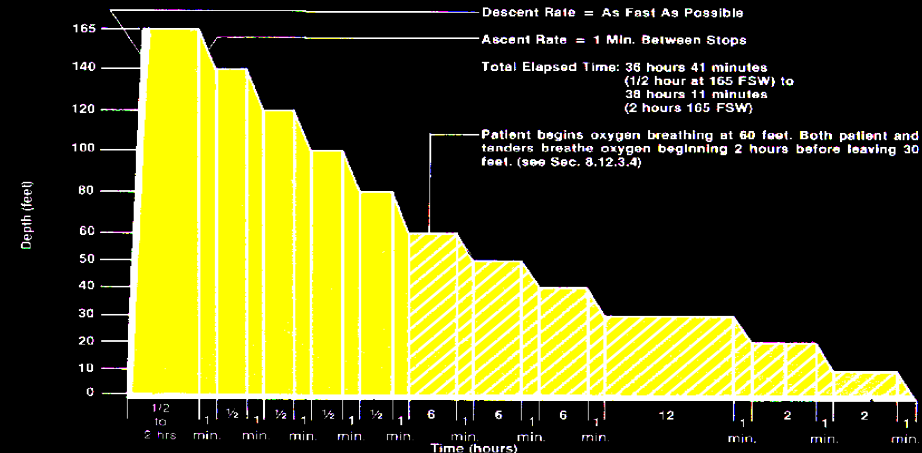
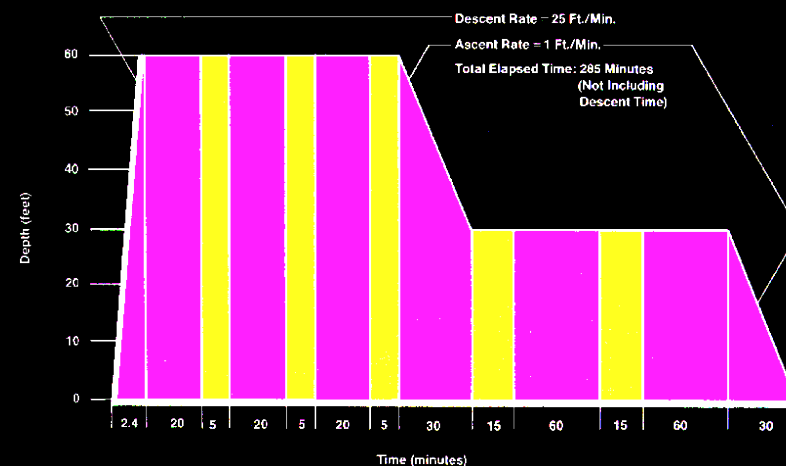
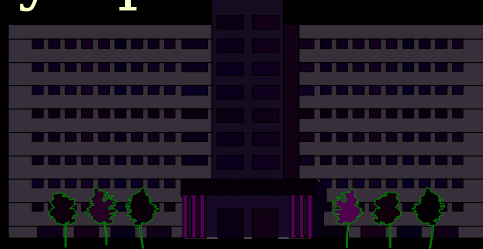


TABLE 6 DEPTH/TIME PROFILE



Medical Management of DCS (With No Chamber Available)

- Make phone contact with the nearest hyperbaric physician and being arrangements for immediate transport to the chamber.
- The patient should be kept on 100 percent oxygen by aviators mask while awaiting and during transportation to the chamber.
- Any patient with Symptoms or signs of neurological DCS, chokes, or shock should be immediately transported to the nearest chamber regardless of whether or not the symptoms persist.



Medical Management of DCS (With No Chamber Available)

- Air transportation must be at or near sea level (14.7psi) pressure. Aircraft used for movement must possess this pressurization capability.



- The use of a pressurized aircraft is ideal, but if a helicopter or other unpressurized aircraft is used, a maximum flying altitude of 1000 feet (14.17psi) should never be exceeded.



- Oxygen should be administered by a tight fitting mask and used continuously during flight.

AEROMEDICAL DISPOSITION of DCS (AEROMEDICAL CONCERNS)



- Residual neurologic/neuropsychologic impairment is a safety of flight issue. Most, but not all individuals who have suffered DCS will make a full recovery and are not at increased risk for recurrent DCS.

AEROMEDICAL DISPOSITION of DCS (WAIVER)

- All **Type I** patients should be grounded 72 hours.
 - Upon full recovery, Type I DCS (single episode) in all classes is considered fully qualified. 
- All **Type II** patients should be grounded for one month.
 - Type II DCS is considered disqualifying, with waivers considered on a case by case basis. Waivers are frequently granted for rated aviation personnel.
 - Exceptions to policy (EP) have never been granted for initial flight applicants with a history of recurrent Type I DCS or Type II DCS.

AEROMEDICAL DISPOSITION of DCS (INFORMATION REQUIRED)

- A Hyperbaric/Diving Medical Officer or neurology consultation and, where behavioral or cognitive symptoms or findings were part of the presentation, neuropsychologic testing ("Cog screen", MMPI, Halstead-Reitan and WAIS-R) are required.

AEROMEDICAL DISPOSITION of DCS (FOLLOW-UP)



- No follow-up is required unless the aircrew member has a recurrent DCS event or has residual abnormalities which require monitoring.

CHAMBERS WITH 24' ASSISTANCE

- ***DAN Duke University (919) 684-8111***
- Naval Operational & Aerospace Medicine, Pensacola, FL DSN 922-4354 or (850) 452-2252/4354
- Naval Diving and Salvage Training, Panama City, FL DSN 436- (850) 234-4651
- Brooks AFB (210) 536-294





Any Questions